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S stars in the Gaia era: stellar parameters and nucleosynthesis

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Abstract. S stars are s-process and C-enriched ($0.5<C/O<1$) red giants. Their abundances can be determined thanks to a new grid of MARCS model atmospheres covering their whole parameter range. Detailed abundance determinations in intrinsic S stars (TP-AGB) and extrinsic S stars (binary masqueraders) can provide strong constraints on the s-process nucleosynthesis: in particular, the s-process temperature can be determined using zirconium and niobium abundances, independently of stellar evolution models. Synthetic spectra of dwarf S stars have been computed and will be sought for in spectroscopic survey data, constraining their luminosity thanks to Gaia parallaxes.

Keywords. Nuclear reactions, nucleosynthesis, abundances; stars: AGB and post-AGB; stars: atmospheres; stars: abundances.

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1. Introduction

S-type stars have effective temperatures similar to those of M-type stars, but show prominent ZrO molecular bands besides the TiO bands typical of M-type stars. Roughly 50% of S stars are *intrinsic*, i.e. thermally-pulsing asymptotic giant branch (TP-AGB) stars experiencing thermal pulses and third dredge-up episodes, while the remaining 50% are *extrinsic* and owe their overabundances to a pollution from a binary companion, formerly a TP-AGB star, now an extinct WD. Intrinsic S stars are enriched in technetium, while Tc has completely decayed in extrinsic S stars ($\tau_{1/2}(^{99}\mathrm{Tc}) = 0.21 \times 10^6$ yrs).

2. S star model atmospheres

A grid of MARCS model atmospheres (Gustafsson *et al.*, 2008) has been computed for S and SC stars (Van Eck *et al.* 2017) covering a five-dimensional parameter space: 2700K$<$ Teff $<$4000K (step 100K); $\log g = 0 - 5$ (step of 1), C/O (from 0.5 to 0.99); [s/Fe] (from 0 to +2 dex), and [Fe/H] (0 or -0.5). Parameters are derived from a comparison between synthetic and observed spectra (Mercator HERMES, Raskin *et al.* 2011) and photometric colors (Geneva, SAAO). Synthesis of dwarf S star spectra has been attempted (Fig. 1). Given the lack of a currently available LaO linelist, the only prominent differences between dwarf M and S stars are (i) the ZrO bands at 6400Å and (ii) the ZrO band at 9300Å ($\Delta\nu$=0). The latter, unfortunately, coincides with the H_2O (201-000) band at 9360±150Å, and separating the strong telluric component from the weak stellar absorption is by no means easy. Therefore, distinguishing S and M dwarfs is not trivial.

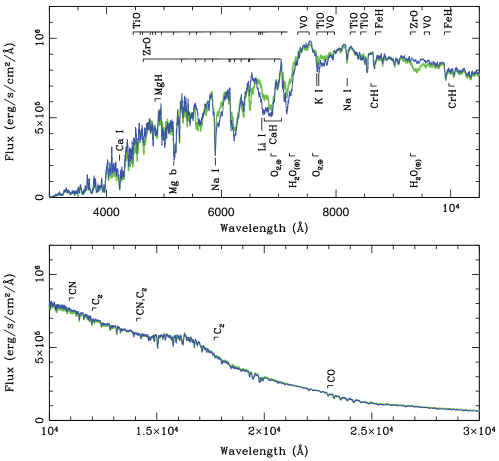

Figure 1. Example of synthetic low-resolution spectra: thick green line: dwarf S star (Teff=3800 K, log g=4, C/O=0.75, [s/Fe]=1); thin blue line: dwarf M star (Teff=3800 K, log g=4, C/O=0.50, [s/Fe]=0).

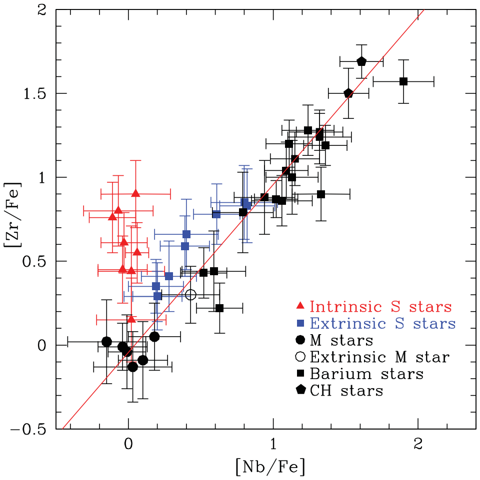

Figure 2. [Zr/Fe] and [Nb/Fe] for intrinsic and extrinsic S stars, barium stars, non-enriched M giants (used as reference), and a slightly enriched M giant labelled as 'extrinsic M star'.

3. Niobium and zirconium abundances: a thermometer

Since ^{93}Zr decays ($\tau_{1/2}$ = 1.53 Myr) into mono-isotopic Nb, the Nb abundance represents a new powerful diagnostic to separate the families of intrinsic and extrinsic stars, besides the original method based on Tc detection only. Indeed, Fig. 2 is an update of Neyskens *et al.* (2015) including a new, extended sample of extrinsic stars. It shows that Tc-rich stars (intrinsic S stars) are Nb-poor, while Tc-poor stars (extrinsic S stars and barium stars) are Nb-rich.

For extrinsic stars it can be demonstrated (Neyskens *et al.* 2015) that, when the abundance of the s-processed material dominates over the initial composition:

$$\left[\frac{\mathrm{Zr}}{\mathrm{Fe}}\right] = \left[\frac{\mathrm{Nb}}{\mathrm{Fe}}\right] + \log\frac{N_s(\mathrm{Zr})}{N_s(\mathrm{Nb})} - \log\frac{N_\odot(\mathrm{Zr})}{N_\odot(\mathrm{Nb})}. \tag{3.1}$$

From Fig. 2 it can be seen that, for extrinsic stars, [Zr/Fe] as a function of [Nb/Fe] follows nicely a straight line of slope 1 (red line on Fig. 2). The y-intercept of this straight line allows to determine log $\frac{N_s(\mathrm{Zr})}{N_s(\mathrm{Nb})}$, which is a function of the s-process operation temperature. Therefore Zr and Nb abundances in extrinsic stars provide a sensitive s-process thermometer.

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